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Wei et al.

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(54) **SYSTEM, METHOD, AND APPARATUS FOR AFTERTREATMENT SYSTEM MONITORING**

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(52) **U.S. Cl.**
CPC ***F01N 3/10*** (2013.01); ***F01N 3/208*** (2013.01); ***F01N 11/00*** (2013.01);
(Continued)

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CPC F02D 41/029; F01N 3/0842; F01N 3/035; F01N 13/02
USPC 60/273, 274, 285, 286, 295, 301
See application file for complete search history.

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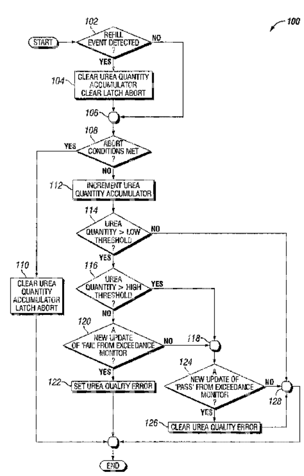
(57) **ABSTRACT**

A method includes determining whether a urea refill event is detected, and clearing a quality accumulator value and clearing a latching abort command. The method includes determining whether urea fluid quality check abort conditions are met, and clearing the urea quality accumulator, latching the abort command, and exiting the reductant fluid quality check. In response to the abort conditions not being met, incrementing the urea quality accumulator according to an amount of urea being injected, and comparing the accumulated urea quantity to a low test threshold. The method includes, in response to the accumulated urea quantity being greater than the low test threshold, comparing the accumulated urea quantity to a high test threshold, and in response to the urea quantity being greater than the high test threshold, determining whether the a NO_x exceedance is observed and clearing a urea quality error in response to the NO_x exceedance not being observed.

20 Claims, 9 Drawing Sheets



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F01N 3/20 (2006.01)
F01N 11/00 (2006.01)

(52) **U.S. Cl.**
CPC *F01N 2550/05* (2013.01); *F01N 2610/02* (2013.01); *F01N 2610/142* (2013.01); *F01N 2900/1806* (2013.01); *F01N 2900/1814* (2013.01); *F01N 2900/1818* (2013.01); *Y02T 10/24* (2013.01); *Y02T 10/47* (2013.01)

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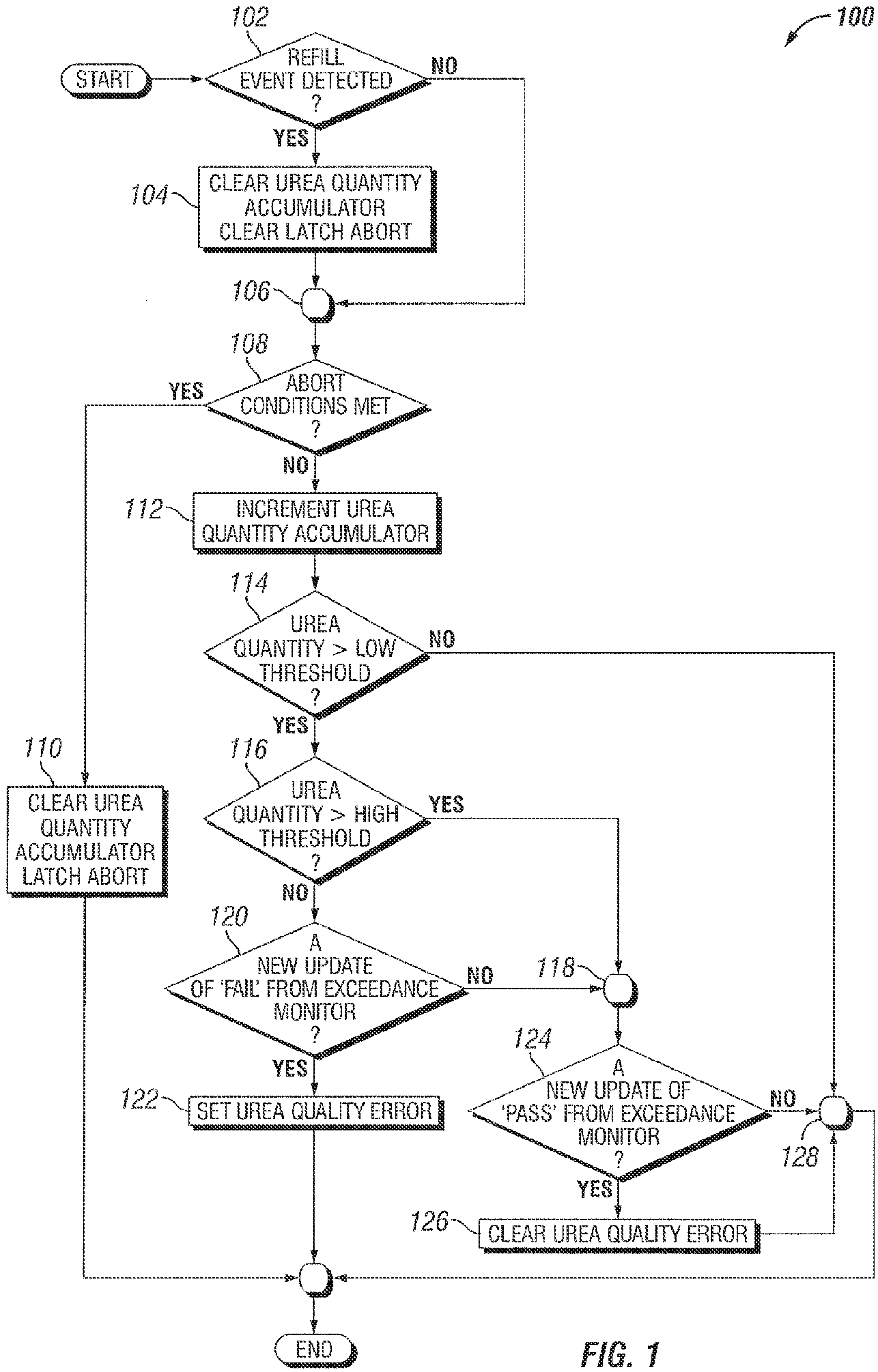

100
START
102
REFILL EVENT DETECTED ?
NO
YES
104
CLEAR UREA QUANTITY ACCUMULATOR CLEAR LATCH ABORT
106
108
ABORT CONDITIONS MET ?
YES
NO
112
INCREMENT UREA QUANTITY ACCUMULATOR
114
UREA QUANTITY > LOW THRESHOLD ?
NO
YES
116
UREA QUANTITY > HIGH THRESHOLD ?
YES
NO
110
CLEAR UREA QUANTITY ACCUMULATOR LATCH ABORT
120
A NEW UPDATE OF 'FAIL' FROM EXCEEDANCE MONITOR ?
NO
118
YES
124
A NEW UPDATE OF 'PASS' FROM EXCEEDANCE MONITOR ?
NO
128
YES
122
SET UREA QUALITY ERROR
126
CLEAR UREA QUALITY ERROR
END

FIG. 1

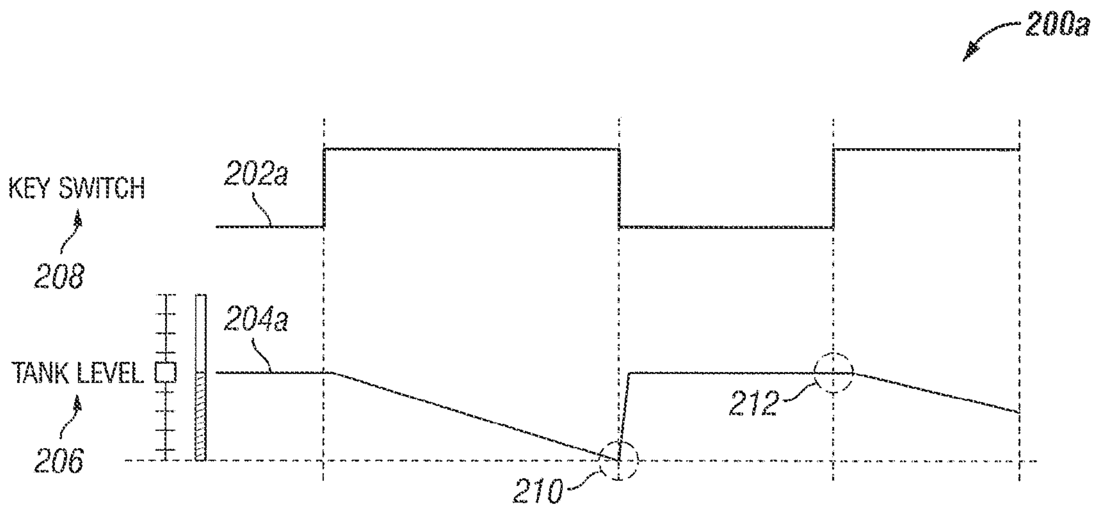

200a
KEY SWITCH
208
202a
204a
TANK LEVEL
206
210
212

FIG. 2A

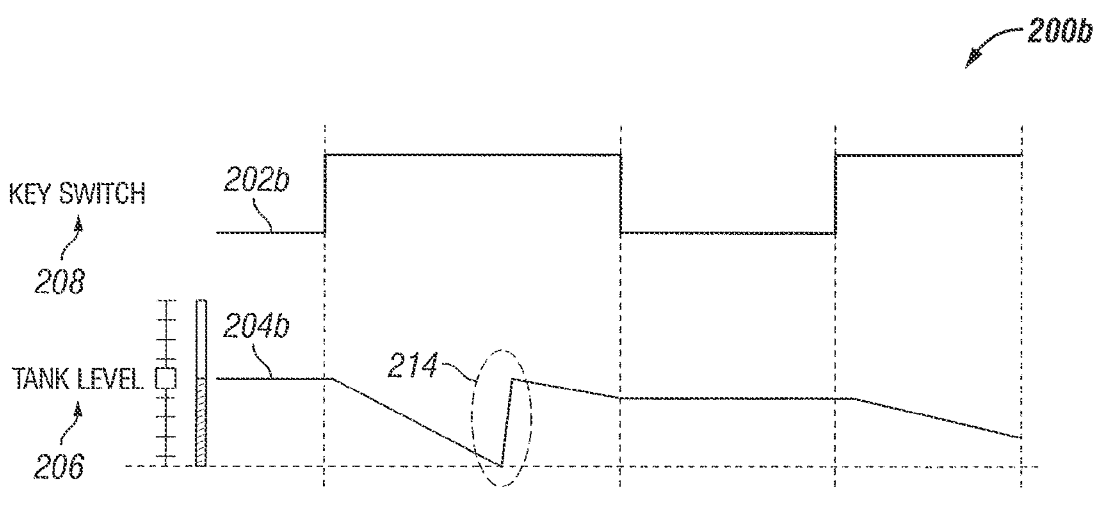
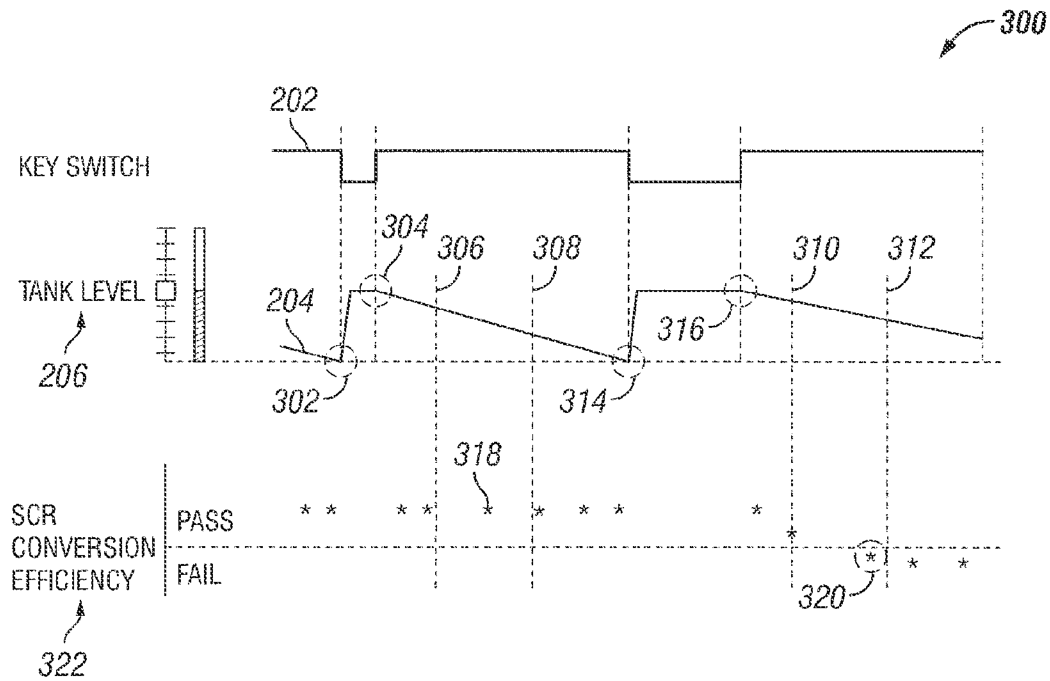
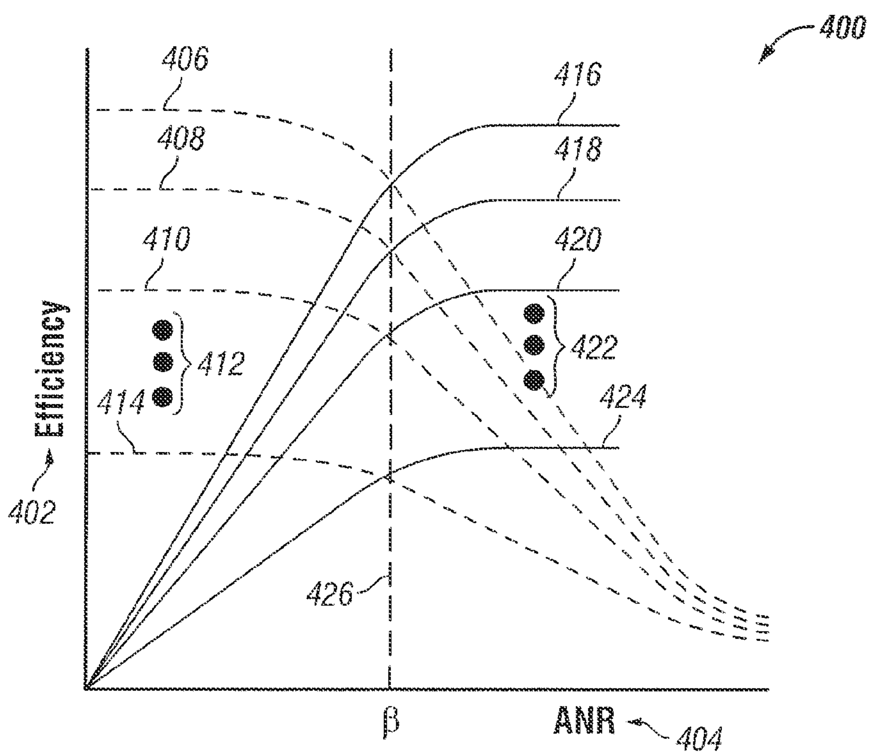

200b
KEY SWITCH
208
202b
204b
TANK LEVEL
206
214

FIG. 2B



300
202
KEY SWITCH
304
306
308
310
312
TANK LEVEL
204
316
206
302
314
318
SCR
CONVERSION
EFFICIENCY
PASS
FAIL
320
322

FIG. 3



400
406
416
408
418
410
420
412
422
414
424
Efficiency
402
426
β
ANR
404

FIG. 4

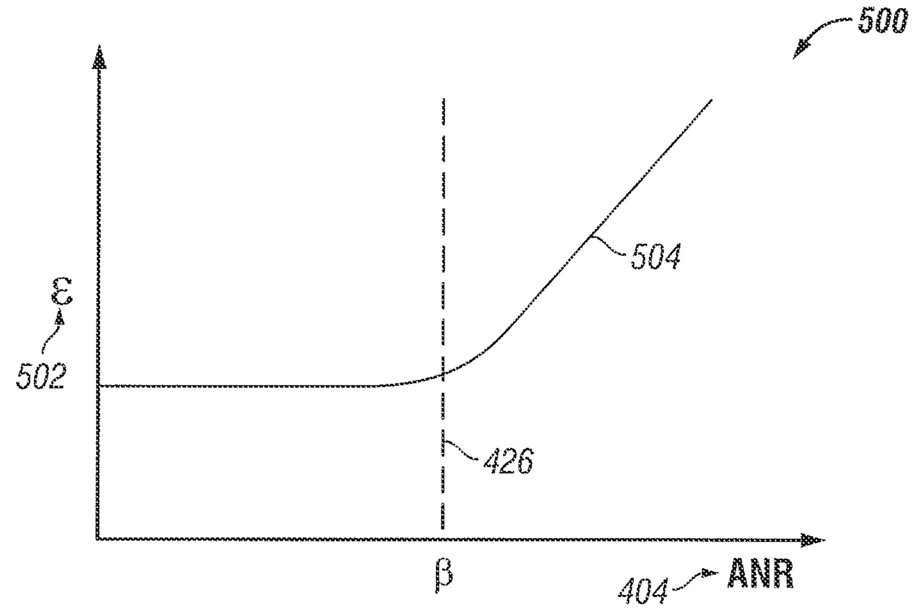


FIG. 5

600

602 ε	604 NORMALIZED η	606 FAULT
FAIL	FAIL	COMPONENT FAILURE: CATALYST, DOSING, OR REDUCTANT
FAIL	PASS	COMPONENT FAILURE: DOSING OR REDUCTANT
PASS	FAIL	COMPONENT FAILURE: CATALYST OR REDUCTANT
PASS	PASS	PASS

FIG. 6

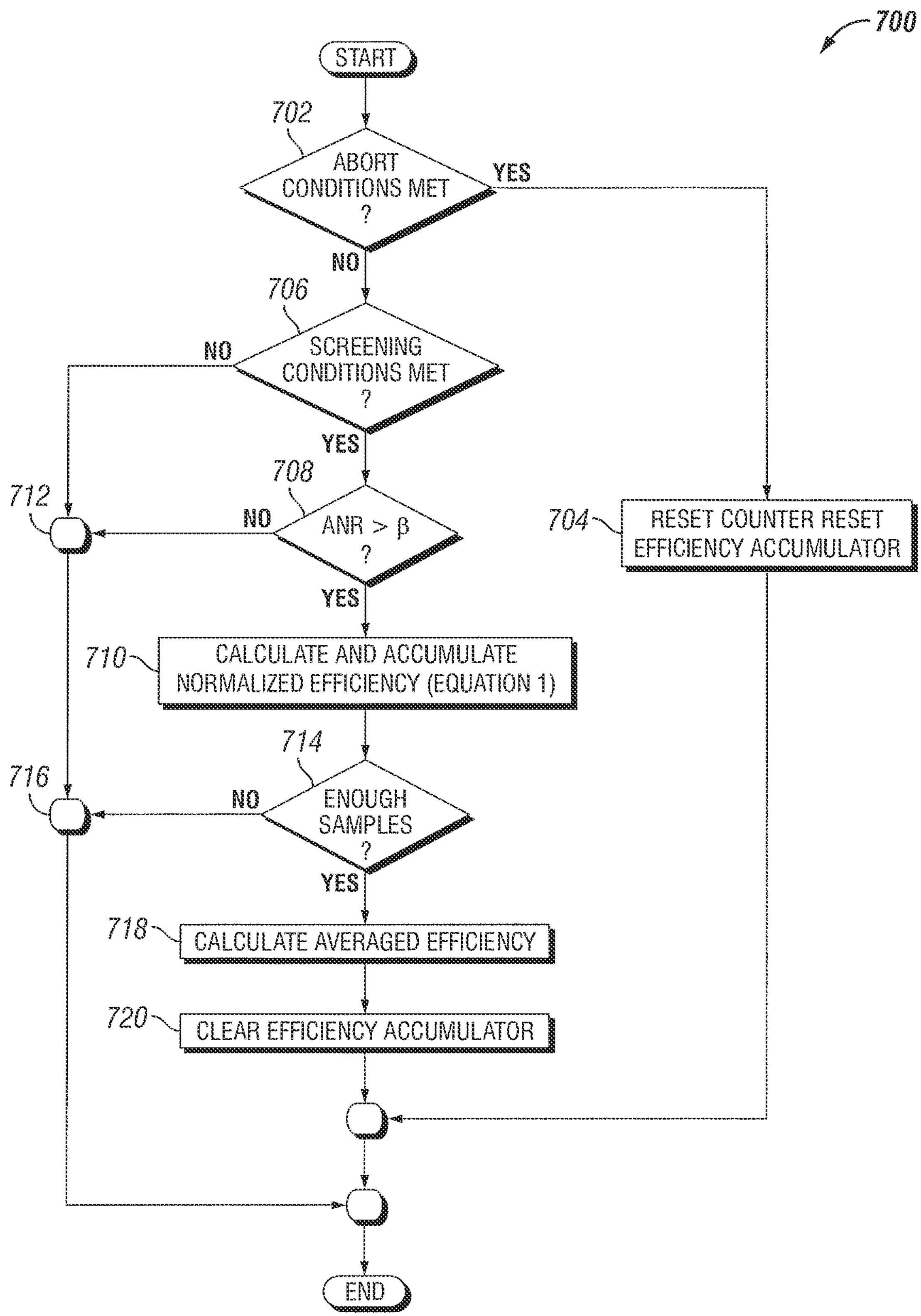

700
START
702
ABORT CONDITIONS MET ?
YES
NO
706
SCREENING CONDITIONS MET ?
NO
YES
708
ANR > β ?
NO
YES
712
704
RESET COUNTER RESET EFFICIENCY ACCUMULATOR
710
CALCULATE AND ACCUMULATE NORMALIZED EFFICIENCY (EQUATION 1)
714
ENOUGH SAMPLES ?
NO
YES
716
718
CALCULATE AVERAGED EFFICIENCY
720
CLEAR EFFICIENCY ACCUMULATOR
END

FIG. 7

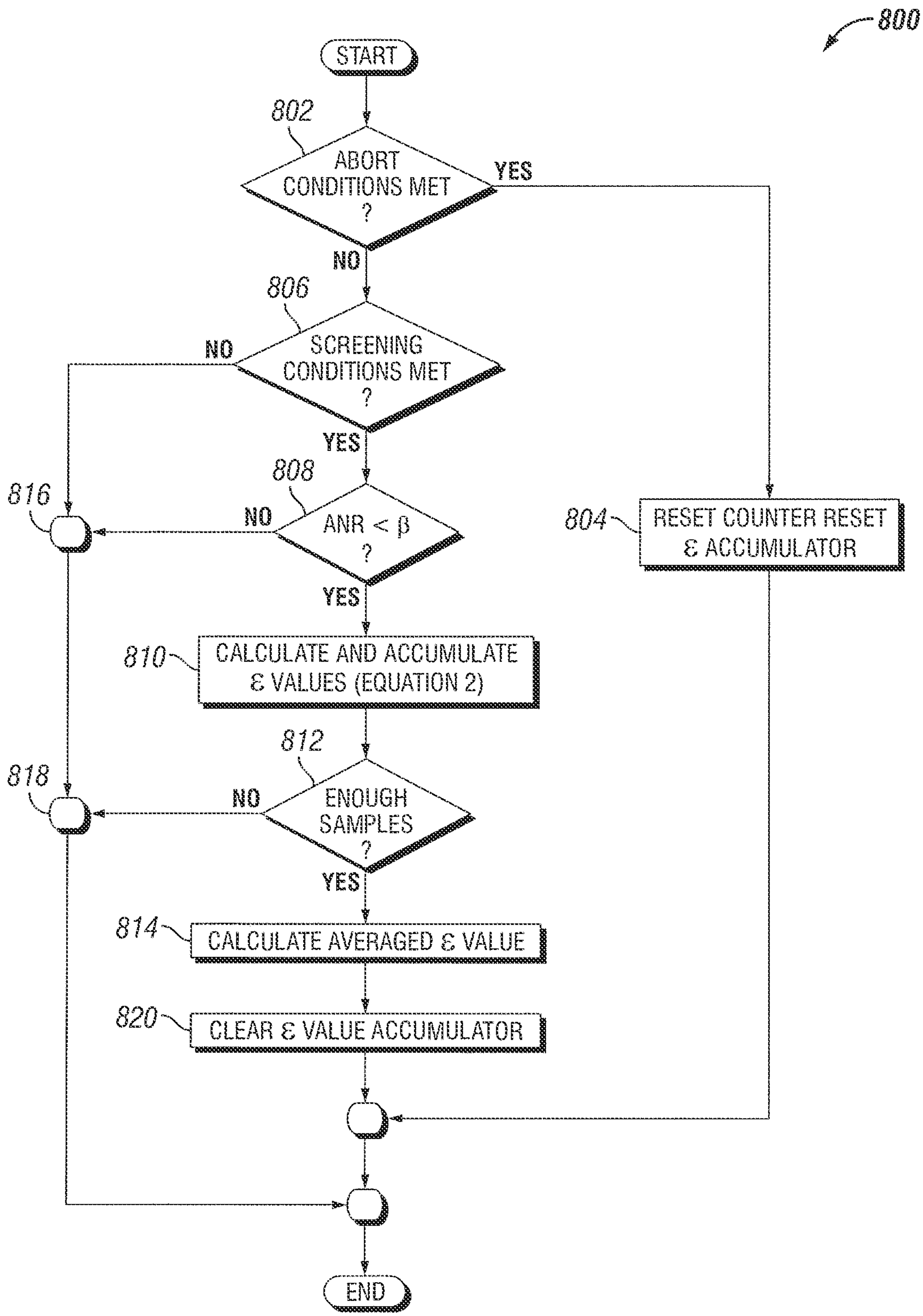

800
START
802
ABORT CONDITIONS MET ?
YES
NO
806
SCREENING CONDITIONS MET ?
NO
YES
808
ANR < β ?
NO
YES
816
804
RESET COUNTER RESET ε ACCUMULATOR
810
CALCULATE AND ACCUMULATE ε VALUES (EQUATION 2)
812
ENOUGH SAMPLES ?
NO
YES
818
814
CALCULATE AVERAGED ε VALUE
820
CLEAR ε VALUE ACCUMULATOR
END

FIG. 8

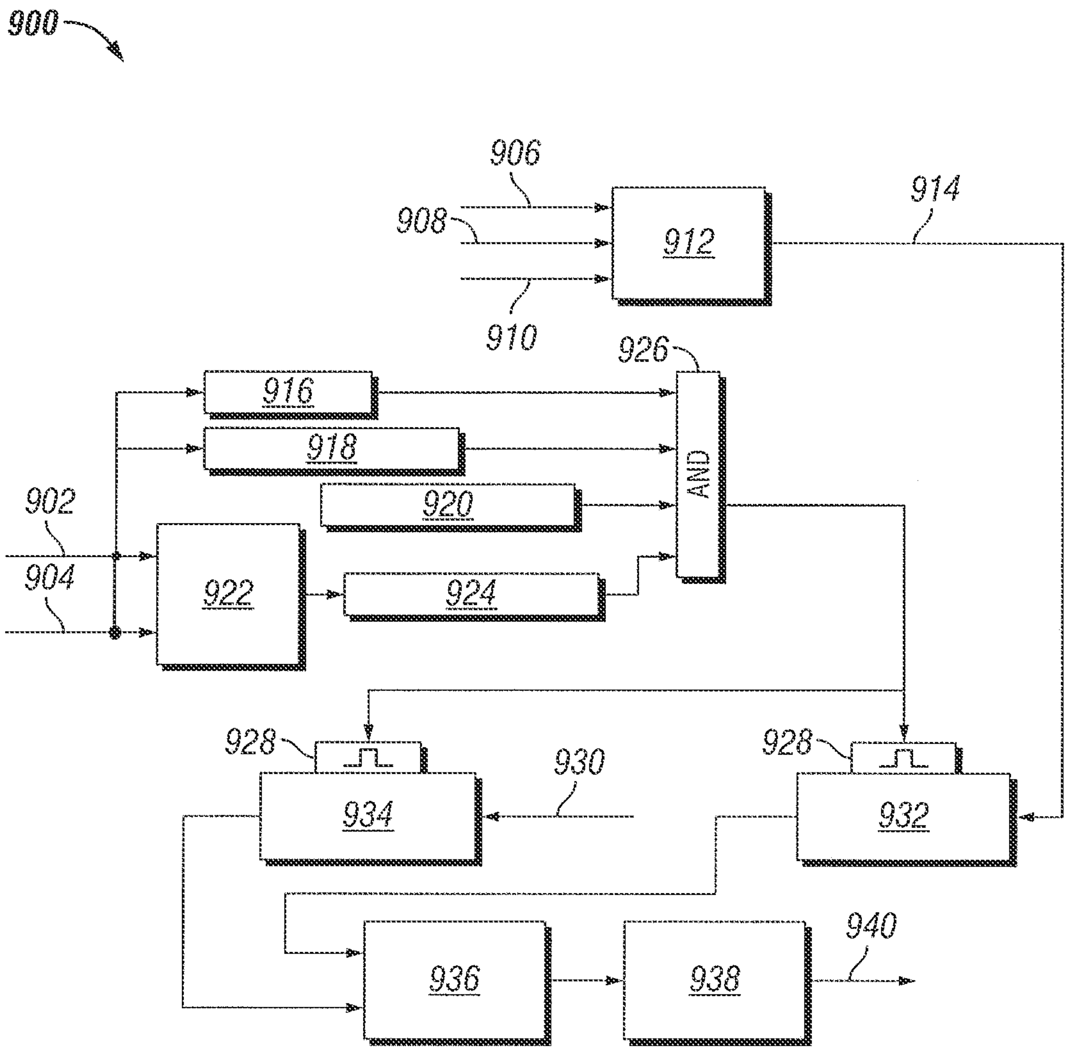

900
906
908
910
912
914
916
918
920
922
924
926
AND
902
904
928
930
928
934
932
936
938
940

FIG. 9

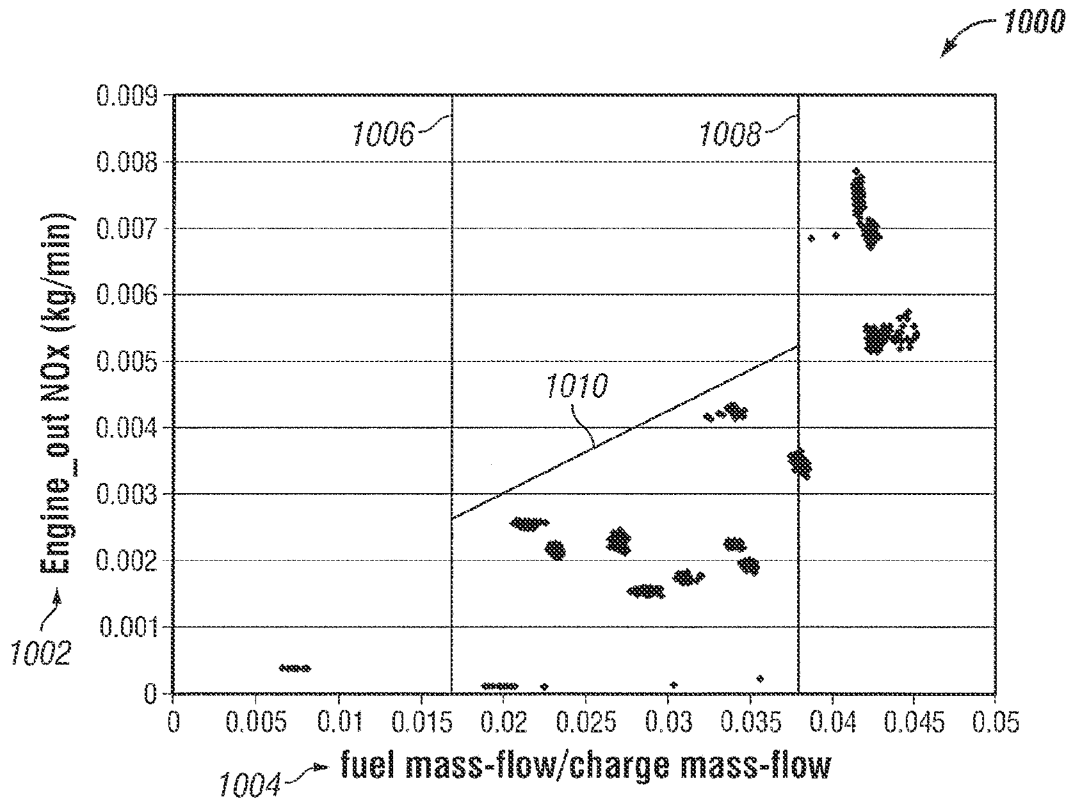

1000
Engine_out NOx (kg/min)
1002
fuel mass-flow/charge mass-flow
1004
1006
1008
1010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

FIG. 10

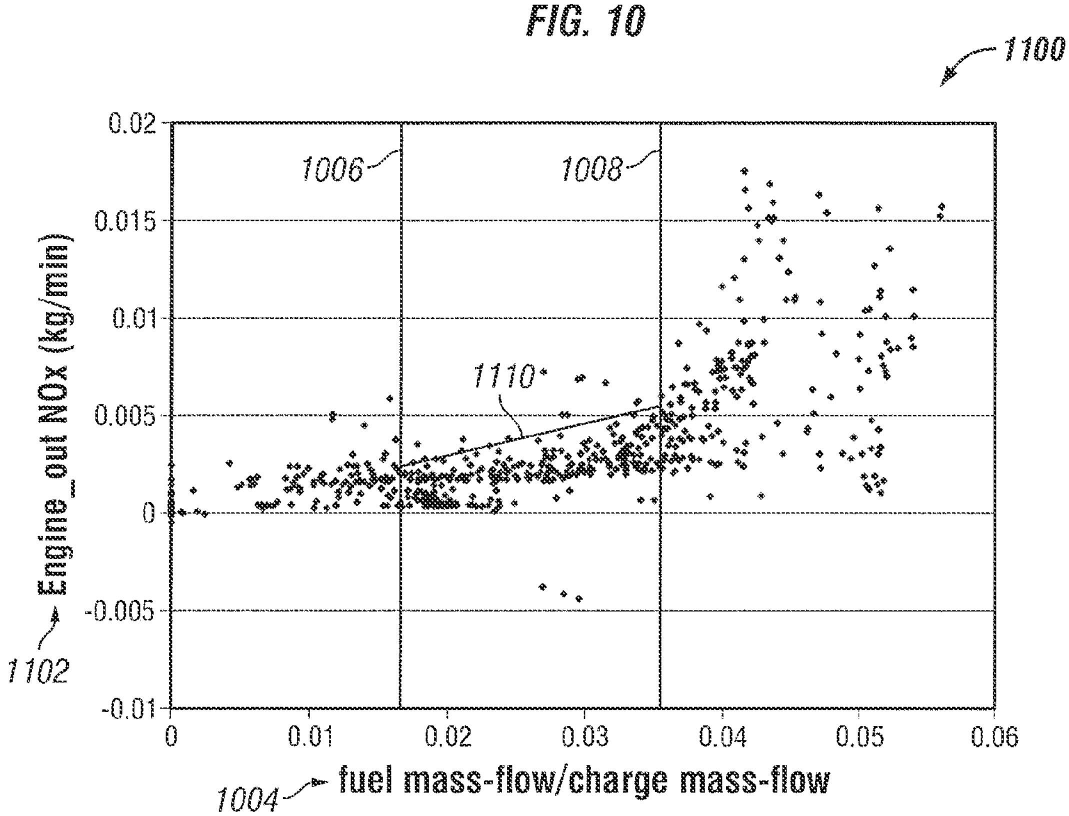

1100
Engine_out NOx (kg/min)
1102
fuel mass-flow/charge mass-flow
1004
1006
1008
1110
0.02
0.015
0.01
0.005
0
-0.005
-0.01
0.01
0.02
0.03
0.04
0.05
0.06

FIG. 11

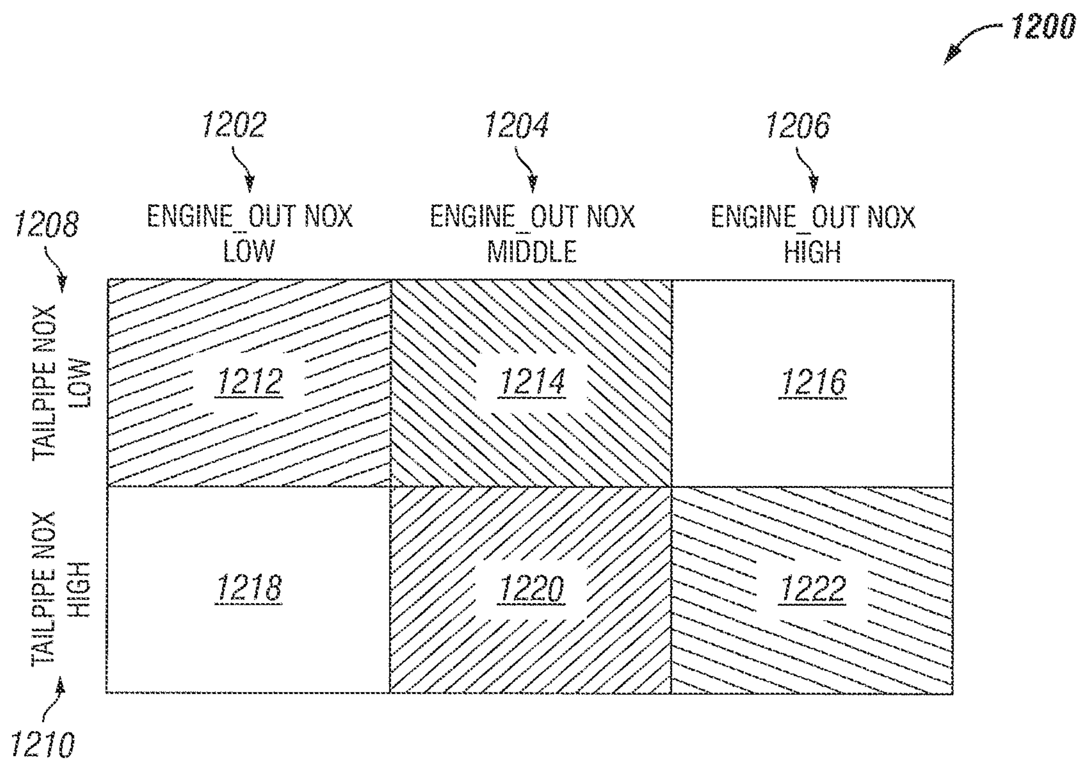

1200
1202
1204
1206
ENGINE_OUT NOX LOW
ENGINE_OUT NOX MIDDLE
ENGINE_OUT NOX HIGH
1208
TAILPIPE NOX LOW
1210
TAILPIPE NOX HIGH
1212
1214
1216
1218
1220
1222

FIG. 12

SYSTEM, METHOD, AND APPARATUS FOR AFTERTREATMENT SYSTEM MONITORING

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of International Application PCT/US2012/032436 filed on Apr. 5, 2012, which claims priority to Provisional Application No. 61/472,177 filed on Apr. 5, 2011, each of which is incorporated herein by reference in its entirety.

BACKGROUND

The technical field generally relates to aftertreatment systems for internal combustion engines. The introduction of aftertreatment systems into the exhaust systems of internal combustion engines also introduces a number of related challenges and drawbacks.

In one example, a NO_x reduction system provides a capability to reduce NO_x emissions from the engine. However, it is desirable to detect whether the NO_x reduction system is properly or sufficiently reducing NO_x gases. One method to determine whether the NO_x reduction system is operating properly is to put a NO_x sensor downstream of the NO_x reduction system. However, in certain engine operating conditions, the system will be operating properly, yet the engine will be producing enough NO_x that the NO_x sensor detects NO_x output and the system may appear to be in a failed condition. At certain engine operating conditions, the engine may be producing a small amount of NO_x such that even a failed NO_x reduction system is capable of converting virtually all of the presented NO_x and the system may appear to be operating properly.

Certain systems for aftertreatment rely upon an active component (e.g. a selective reduction catalyst (SCR) component), upon a reagent (e.g. urea to provide NH_3 to the SCR component), and/or upon a reagent delivery system (e.g. a reagent injector). Certain failures of these systems produce failures that are difficult to detect, and/or difficult to identify a source of the failure. For example, it is challenging to distinguish between a failed catalyst on the SCR component, a failed reagent (e.g. a urea reagent container erroneously or improperly filled with water), and a failed reagent delivery system.

Certain systems for aftertreatment rely upon having both upstream and downstream NO_x measurement of the reduction catalyst to determine if the catalyst NO_x conversion has degraded. Certain systems for aftertreatment rely upon inlet NO_x determinations and reductant injection rate determinations that have high accuracy and precision to determine if the catalyst NO_x conversion efficiency has degraded.

Therefore, further technological developments are desirable in this area.

SUMMARY

One embodiment is a unique method for determining a NO_x reduction system failure. Other embodiments include unique methods and systems for distinguishing the failed component in the NO_x reduction system. This summary is provided to introduce a selection of concepts that are further described below in the illustrative embodiments. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic flow diagram of a procedure for detecting a reductant fluid quality error.

FIG. **2**A illustrates an exemplary timeline for detecting a reductant fluid refill event.

FIG. **2**B illustrates a second exemplary timeline for detecting a reductant fluid refill event.

FIG. **3** illustrates a timeline for detecting a reductant fluid quality error.

FIG. **4** illustrates exemplary deNO_x efficiency and deNH_3 efficiency values plotted against ANR for a NO_x reduction system.

FIG. **5** illustrates an epsilon (ϵ) value plotted against ANR for a NO_x reduction system.

FIG. **6** depicts an exemplary behavior table for a NO_x reduction system diagnostic procedure.

FIG. **7** is a schematic flow diagram of a procedure for determining an average deNO_x efficiency.

FIG. **8** is a schematic flow diagram of a procedure for determining an averaged ϵ value.

FIG. **9** is a schematic flow diagram of a procedure for monitoring a NO_x reduction system NO_x conversion amount.

FIG. **10** provides an illustrative estimated NO_x, high NO_x threshold, and low NO_x threshold value.

FIG. **11** provides an illustrative estimated NO_x, high NO_x threshold, and low NO_x threshold value, with a NO_x value plotted on a logarithmic axis.

FIG. **12** depicts an exemplary behavior table for a NO_x reduction system monitoring procedure.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, any alterations and further modifications in the illustrated embodiments, and any further applications of the principles of the invention as illustrated therein as would normally occur to one skilled in the art to which the invention relates are contemplated herein.

Referencing FIG. **1**, an example procedure **100** for performing a reductant fluid quality check is depicted. The procedure **100** includes an operation **102** to determine whether a refill event is detected. If the refill event is detected, at operation **104** a urea quality accumulator value is cleared (e.g. reset to zero) and a latching abort command is cleared, allowing the reductant fluid quality check to proceed. The latching abort command indicates that, once the abort command is set, the abort command value is held at the same value until updated by another operation.

In response to the refill event not being detected, the procedure **100** bypasses operation **104** to continuation **106**, and the procedure further includes an operation **108** to determine whether abort conditions are met. In response to the abort conditions being met, the check includes an operation to clear the urea quantity accumulator, clear the latching abort command, and exit the check. Example operations to determine whether the abort conditions are met include checking the latching abort command, and checking whether a fault is present. Example faults that cause the reductant fluid quality check to abort include a temperature sensor fault, a NO_x sensor fault, a reductant injector fault, and/or a reductant tank level fault. Additionally or alternatively, any fault in the system that renders an engine-out NO_x estimate, a reduction catalyst NO_x conversion efficiency estimate, and/or an injected amount of reductant (relative to a commanded amount of reductant) to be sufficiently uncertain is a fault that can be utilized to abort the reductant fluid quality check.

The reductant fluid quality check continues, when no abort condition is met, by an operation **112** to increment a urea quantity accumulator (or reductant quantity accumulator) according to an amount of urea being injected. The procedure **100** includes an operation **112** to compare the output of the urea quantity accumulator, the urea quantity, to a low test threshold, and if the urea quantity is less than the low test threshold the current execution cycle of the reductant fluid quality check is exited through continuation **128**. If the urea quantity is greater than the low test threshold, the test is continued with an operation **116** to compare the urea quantity to a high test threshold.

In response to the urea quantity being greater than the high test threshold, the procedure **100** includes an operation **124** to determine whether the urea quality check can be determined to be a PASS value. The operation **124** is determined to be a PASS value when no NO_x exceedance is observed. If the operation **124** is determined to be a PASS value, the procedure **100** includes an operation **126** to clear any urea quality error before proceeding to continuation **128** and exiting.

In response to the urea quantity being lower than the high test threshold, the procedure **100** includes an operation **120** to determine whether the check can be determined to be a FAIL value. If the check is determined to be a FAIL value, the procedure includes an operation **122** to set a urea quality error (or reductant fluid quality error), if present. An example operation **120** determines the check to be a FAIL value when a NO_x exceedance is observed.

Referencing FIGS. **2**A and **2**B, illustrative data demonstrating an operation to detect a refill event is depicted. The curve **202***a* illustrate the state of the key switch **208**, with a high vertical position indicating an "ON" key switch and a low vertical position indicating an "OFF" key switch. The curve **204***a* indicates the output of the urea tank level **206** (or reductant tank level), for example from a urea tank level sensor.

The exemplary operation includes a detection in response to a fill-up during a key off event (or other controller shutdown event wherein, during the period of the shutdown, a signal from a reductant tank level sensor is unavailable) illustrated in the top timeline. At a first time **210** the urea tank level is shown to be low at a time when a key switch is turned off. In the example of the upper timeline, the signal from the urea tank level is unavailable while the keyswitch remains off. The signal is resumed at a second time **212**, and when the urea tank level is determined to be high, a refill event is detected.

The difference between the low and the high tank levels that is required to determine that a refill event has occurred may be any amount, including any minimally significant amount up to an amount requiring that the tank be substantially filled with new reductant fluid before a refill event is detected. For example, the refill event may detect top-off events where a minor but significant amount of urea is added, only events from a threshold low level to ensure that most of the present urea is newly added urea, or events where a specified percentage of the entire capacity of the urea tank is added (e.g. 10%, 20%, 50%, or other value). One of skill in the art will recognize that requiring more complete refills improves the reliability of a given reductant fluid quality check to properly determine the NO_x reduction capacity of the replacement reductant fluid, but it will also reduce the number of opportunities to perform a reductant fluid quality check, as partial fill-ups of insufficient size to trigger a refill detection will extend the time period between checks.

Referencing FIG. **2**B illustrative data demonstrates an operation to detect a refill event. In the operations of the lower timeline, while the key switch remains on and the urea tank level signal remains active, a fill up event occurs at the time period **214**. In certain embodiments, when a urea tank level increase is detected, an initial urea tank level and a final urea tank level are determined according to when the tank level rise begins and ends, and/or according to when the tank level rise begins and a tank level decrease begins. According to the difference between the final and initial urea tank levels, a refill event may be detected. The amount of rise determined to be a refill event is determined under similar considerations for an embodiment utilizing FIG. **2**B or FIG. **2**A.

Referencing FIG. **3**, example operations of a reductant fluid quality check procedure are shown on a timeline of illustrative data **300**. The upper data timeline indicates the "DEF" tank level (diesel exhaust fluid), which may be a level of any reductant fluid. The lower timeline indicates an asterisk **318**, **320** at each reductant fluid quality check result. Certain ones of the reductant fluid quality check results are utilized, and certain others of the reductant fluid quality check result are ignored. At the bounded times **302**, **304** in the upper timeline, a refill event is detected due to the rise in the DEF tank level.

Referencing the lower timeline, test data points occurring before the DEF tank refill event are ignored and the test results are not used to set or clear a reductant fluid quality error. After the DEF tank refill event, the test data points are likewise ignored until an amount of reductant is injected that exceeds the low test threshold—occurring at time **306** in the illustration. The test continues until the high test threshold amount of reductant is injected, occurring at time **308** in the illustration. The test point **318** that occurs between the times **306**, **308** is utilized, and since a sufficient SCR conversion efficiency **322** is demonstrated reductant fluid quality error is cleared, reset, decremented, or other actions are taken consistent with a passed check on the NO_x reduction system. In the example embodiment, test values occurring later than the high test threshold may be ignored, or may be utilized to clear or decrement a reductant fluid quality error. In one form, test values occurring later than the high test threshold are not utilized to increment or set the reductant fluid quality error.

Further in FIG. **3**, a second DEF tank refill event occurs between times **314**, **316**. The low test threshold amount of urea injected is passed at time **310** in the example, and the high test threshold amount of urea injected is passed at time **312** in the example. A test value **320** indicates that a NO_x exceedance event occurred. The test value **320** occurs before the high test threshold is reached, and a reductant fluid quality error is set or incremented, or other actions are taken consistent with a failed check on the NO_x reduction system. In the example of FIG. **3**, the two test values occurring after the high test threshold is reached are not utilized.

An example procedure for determining whether an aftertreatment deNO_x system failure is present and for determining the source of the deNO_x system failure is described following. The example procedure for determining the deNO_x system failure and source may be combined with other procedures to eliminate potential causes for system failure and/or performance degradation.

The exemplary procedure includes determining a deNO$_x$ efficiency within a temperature and exhaust flow range where the deNO$_x$ efficiency has a reduced sensitivity to variation and uncertainty in the sensing values. The procedure includes determining a normalized deNO$_x$ efficiency, which includes a ratio between measured deNO$_x$ efficiency and expected deNO$_x$ efficiency, such as shown in Equation 1. The normalized deNO$_x$ efficiency is calculated for the data points with an ammonia to NO$_x$ ratio (ANR) higher than a stoichiometric ANR (β).

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out})/NO_{x\_in}}{\eta_{nominal}} \quad \text{(Equation 1)}$$

It has been found that at ANR values above the β value, the deNO$_x$ efficiency is not sensitive to ANR, which reduces the noise introduced from NO$_x$ reduction catalyst inlet NO$_x$ sensing error (or modeled inlet NO$_x$ error) and urea dosing error. Accordingly, the normalized deNO$_x$ efficiency can be more indicative of the effects of the NO$_x$ reduction catalyst and the reductant fluid quality, while helping decouple the effects of inlet NO$_x$ determination errors and reductant injection rate errors. Referencing FIG. **4**, simulated illustrative data is shown illustrating the deNO$_x$ efficiency behavior of various operating curves. The curves **416**, **418**, **420**, and **424** illustrate example deNO$_x$ efficiency values as a function of the ANR, and illustrate that the deNO$_x$ efficiency rises linearly with the ANR over a period of operating points below the β value, begins a non-linear transition region around the β value, at flattens at high ANR values to a value which is not responsive to the ANR at high ANR values. The values **422** represent a number of possible curves that may be determined for a given system, similar to the curves **416**, **418**, etc.

Referencing again FIG. **4**, the curves **406**, **408**, **410**, **414** illustrate example deNH$_3$ efficiency curves corresponding to the deNO$_x$ efficiency curves **416**, **418**, **420**, **424**. The curves for deNO$_x$ efficiency and deNH$_3$ efficiency meet at the β value, or at the stoichiometric point. The values **412** represent a number of possible curves that may be determined for a given system, similar to the curves **406**, **408**, etc. The curves **406**, **408**, **410**, **414** are illustrated to provide a fuller understanding of the catalyst activity in the system.

For the data points with ANR less than β, the procedure includes determining an ϵ value. The ϵ value is defined as the ratio between dosing commands and NO$_x$ removed in the catalyst (see Equation 2). In the example of Equation 2, the ϵ value is a mass balance ratio. For example, as depicted in the illustrative data of FIG. **5**, while the deNO$_x$ efficiency is insensitive to ANR at high ANR values—specifically above β—the ϵ value becomes relatively insensitive to ANR at low values of ANR. The curves **504** depicts the ϵ value as a function of ANR. As depicted in the illustrative data of FIG. **4**, the ϵ value becomes relatively insensitive to ANR at low values of ANR, specifically below β.

$$\varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in/NOx\_in}{(NOx\_in - NOx\_out)/NOx\_in} = \frac{ANR}{DeNOx\_eff} \quad \text{(Equation 2)}$$

When evaluated in the regions where it is insensitive to ANR, the normalized deNO$_x$ efficiency is more sensitive to catalyst deNO$_x$ efficiency deterioration, and decouples engine-out NOx determinations and urea injector errors. Generally, a deteriorated deNOx efficiency will move downward in the curves, for example from operating curve **416** to operating curve **418**. When evaluated in the regions where it is insensitive to ANR, the ϵ value is more sensitive to urea delivery, and decouples catalyst deNO$_x$ efficiency deterioration.

Referencing FIG. **6**, an example logic description to utilize the normalized deNO$_x$ efficiency and the ϵ value is illustrated. In the example of FIG. **6**, where both the deNO$_x$ efficiency and the ϵ value indicate a component failure, the failure is attributable to any of the deNO$_x$ catalyst, the reductant dosing system, or the reductant fluid quality. Where both of the deNO$_x$ efficiency and the ϵ value indicate a PASS, then no component failure is indicated. Where the ϵ value indicates a component failure and the deNO$_x$ efficiency indicates a PASS, the component failure is narrowed to the reductant dosing system or the reductant fluid quality. Where the ϵ value indicates a PASS and the deNO$_x$ efficiency indicates a component failure, the component failure is narrowed to the deNO$_x$ catalyst or the reductant fluid quality.

Referencing FIG. **6**, an illustrative component failure logic **600** is depicted. The component failure logic **600** is helpful to reduce maintenance costs and failure diagnostic time, as well as to separate coupled issues in diagnosing a failed component. Alternatively or additionally, the information from FIG. **6** can be utilized with other information available in the system to further determine which component is failed. For example, if a catalyst temperature excursion is observed immediately before a failure, it may be determined to be more likely to be a failed catalyst than a reductant fluid quality failure. A technician may manually check a reductant fluid quality or a reductant doser system. In one form, a fault present in the reductant doser system, a reductant tank level that is observed to drop as expected over time, results from an active diagnostic performed on the reducant dosing system, and/or any other information available in the system may be utilized with the information from FIG. **6** to determine which component of a NO$_x$ reduction aftertreatment system has failed.

In the example component failure logic **600** of FIG. **6**, a first column **602** depicts an ϵ based failure determination, for example according to Equation 2 and the nominal operations depicted in FIG. **5** or similar information calibrated for a particular system. A second column **604** depicts a normalized deNO$_x$ efficiency based failure determination, for example according to Equation 1 and the deNO$_x$ efficiency curves depicted in FIG. **4** or similar information calibrated for a particular system. In the example logic **600**, where the ϵ indicates a failure and the normalized deNO$_x$ efficiency indicates a failure, the failure is determined to be one of the catalyst, the dosing injector, or the reductant quality, although the diagnostic differences of the ϵ and normalized deNO$_x$ efficiency do not separate these component failures. Where the ϵ indicates a failure, but the normalized deNO$_x$ efficiency does not indicate a failure, the catalyst is understood to be working properly and the component failure is narrowed to a dosing injector or the reductant quality. Where the ϵ indicates a pass and the normalized deNO$_x$ efficiency indicates a failure, the component failure is understood to be either the catalyst or the reductant quality. Where both the ϵ and the normalized deNO$_x$ efficiency indicate a pass, the system is understood to be working correctly. The output of the logic **600** can be combined with other information, for example a reductant quality check such as depicted in FIG. **1**, to further narrow the diagnosis of any failure.

Another example procedure is described for diagnosing whether reductant fluid is proper, diluted, replaced, or otherwise improper. The procedure includes an operation to determine whether a tank refill event is detected. An example operation includes interpreting a reductant tank level value, for example from a tank level sensor, and in response to the reductant tank level value determining the reductant tank is recently filled. The procedure further includes determining a tank refill event in response to the reductant tank level value. In response to the tank refill event, the procedure includes an operation to clear a reductant accumulator value and proceeding with a reductant fluid quality check. The operation also clears an abort latch, such that a check at operation will indicate that abort conditions are not met for the purpose of checking a new urea tank, although other abort conditions may be otherwise met.

The procedure further includes determining a NO_x emissions amount, for example determined from reductant dosing commands, inlet and outlet NO_x levels for a reductant catalyst, an estimated temperature for the reductant catalyst, and an exhaust flow rate for an engine providing the exhaust treated by the reductant catalyst. The inlet and outlet NO_x level values may be determined from a sensor, and the inlet NO_x level may alternatively or additionally be determined from a model. The reductant catalyst temperature may be determined from an inlet sensor, outlet sensor, a mid-brick sensor, and/or from a weighted average of available sensors or a modeled value based upon exhaust and/or turbine outlet temperatures.

The exemplary procedure further includes determining a NO_x exceedance event in response to the NO_x emissions amount. In response to the NO_x exceedance event occurring within a predetermined period after the tank refill event, a reductant fluid quality failure is detected. In certain embodiments, determining the NO_x exceedance event includes accumulating a reductant injected amount during a period of the reductant fluid quality check. In response to the reductant injected amount being lower than a low test threshold, the reductant fluid quality check is exited without conclusion. In response to the reductant injected amount being greater than a high test threshold, the procedure includes an operation to clear any reductant fluid quality error if a NO_x exceedance is not detected. In response to the reductant injected amount being greater than the low test threshold but less than the high test threshold, the procedure includes an operation to set a reductant fluid quality error if a NO_x exceedance is detected, and to clear a reductant fluid quality error if the NO_x exceedance is not detected.

The detection of the NO_x exceedance includes determining that a threshold amount of NO_x is being emitted from the system, where the threshold amount of NO_x is a selected amount of NO_x. Exemplary and non-limiting threshold amounts of NO_x include an amount exceeding an emissions target, an amount exceeding a short-term emissions target, an amount exceeding any other NO_x target value, and/or an amount exceeding any selected target with an added or subtracted estimated margin of error. The margin of error may be added, for example, to ensure that a given NO_x emissions level is actually greater than the NO_x target value. The margin of error may be subtracted, for example, to ensure that a given NO_x emissions level does not exceed the NO_x target value before a reductant fluid quality error is set. The margin of error is a value that may be updated over time, for example to the uncertainty of a NO_x estimate at current operating conditions of the system.

Referencing FIG. **7**, an example procedure **700** for monitoring an aftertreatment system is illustrated. The procedure **700** includes an operation **702** to check whether abort conditions for the procedure are met. Exemplary abort conditions include a fault in a hardware component and/or sensor related to the aftertreatment system, a transient operating condition being present, and a reductant dosing system that is presently available to dose (e.g. no conditions are present that prevent the dosing system from providing reductant during the monitoring procedure). The transient operating condition can be a transient exhaust temperature, exhaust flow, and/or engine-out NO_x level value. In certain embodiments, the presence of steady state operating conditions, or the lack of transient operating conditions, allows the monitoring procedure to proceed. Where abort conditions are present, the procedure includes an operation **704** to reset a counter (a samples taken counter) and an efficiency accumulator.

The procedure **700** further includes an operation **706** to determine whether screening conditions are present. Example screening conditions include determining that an SCR catalyst temperature is within an operating range, determining that an exhaust flow value or a catalyst space velocity is in an operating range, determining that a dosing command is not presently restricted or limited, and/or that a NO_x sensor output is operating within a high confidence regime. Example conditions for the NO_x sensor output to operate in a high confidence regime include the NOx sensor output value being within a rational range, the NOx sensor value being lower than a threshold value (e.g. not near the top of the operating range such that it might become unreliable during the test), that ambient air pressure is within a normal range, that an NH_3 slip estimate is within a normal range, and/or that an NO_2 slip estimate is within a normal range. In certain embodiments, some test screening or testing abort conditions may be characterized as an abort condition or a screening condition. Generally, where a condition should be absent it is characterized as an abort condition for the test to proceed, and where a condition should be present it is characterized as a screening condition for the test to proceed, but such characterizations are not limiting to any particular embodiment, and certain conditions may be an abort condition in certain embodiments and a screening condition in certain embodiments.

The procedure **700** includes an operation **708** to determine whether the present ANR is greater than the β value. The β value is a stoichiometric value of ANR, or a value near stoichiometric wherein the variability in the deNO_x efficiency as a function of the ANR is acceptably low. Where the ANR is below the β value, the procedure **700** exits the current execution cycle through continuations **712**, **716**. Where the ANR is above the β value, the procedure **700** continues with an operation **710** to calculate and accumulate a normalized efficiency value, for example as in Equation 1. The operation **700** to accumulate the normalized efficiency value includes any operation enabling the averaging of a number of normalized efficiency values, including storing a number of efficiency values in a memory buffer, utilizing a filtered or weighted averaged efficiency value that captures historical efficiency value information over a number of efficiency value points, and similar operations understood in the art.

The procedure **700** further includes an operation **714** to determine whether a sufficient number of efficiency value samples have been taken. The operation **714** to determine whether a sufficient number of samples have been taken includes determining whether a predetermined number of samples have been taken, determining whether enough samples have been taken to provide a given statistical confidence in the average of the samples, and/or may further include weighting of the confidence increment provided by each of the samples in response to the particular reliability of a given sample and determining whether the accumulated confidence exceeds a threshold value.

Where the procedure **700** has not resulted in a sufficient number of samples, the procedure **700** exits the current execution cycle through the continuation **716**. Where the procedure **700** has provided sufficient samples, the procedure **700** includes an operation **718** to calculate an averaged efficiency. The operation **718** to calculate the averaged efficiency includes an operation to determine a statistically significant average—for example a mean or median average, an operation to utilize a moving average as the average, and/or an operation to utilize a filtered value as an average. Any other averaging operations understood in the art are contemplated herein. The procedure includes an operation **720** to clear the efficiency accumulator, which may further include resetting any filters, moving averages, or other information history parameters.

Referencing FIG. **8**, an exemplary procedure **800** for monitoring an aftertreatment system is illustrated. The procedure **800** includes an operation **802** to check whether abort conditions for the procedure are met. Exemplary abort conditions include a fault in a hardware component and/or sensor related to the aftertreatment system, a transient operating condition being present, and a reductant dosing system that is presently available to dose (e.g. no conditions are present that prevent the dosing system from providing reductant during the monitoring procedure). The transient operating condition can be a transient exhaust temperature, exhaust flow, and/or engine-out NO_x level value. In certain embodiments, the presence of steady state operating conditions, or the lack of transient operating conditions, allows the monitoring procedure to proceed. Where abort conditions are present, the procedure includes an operation to reset a counter (a samples taken counter) and an ϵ accumulator.

The procedure **800** further includes an operation **806** to determine whether screening conditions are met. The abort conditions and screening conditions of the procedure **800** are similar to but need not be the same as the abort conditions and screening conditions of the procedure **700**. For example, procedure **800** utilizes values of ANR below β, and determines values of ϵ rather than normalized deNO_x efficiency. The criteria, operating ranges of sensors, and operating margin within the operating range of sensors and hardware components, to determine whether ϵ can be reliably determined and an ϵ-based test successfully completed can differ from the same parameters for a deNO_x efficiency based test.

The procedure **800** includes an operation **808** to determine whether the present ANR is less than the β value. The β value is a stoichiometric value of ANR, or a value near stoichiometric wherein below the β value the variability in the ϵ as a function of the ANR is acceptably low. Where the ANR is above the β value, the procedure exits the current execution cycle through the continuations **816**, **818**. Where the ANR is below the β value, the procedure **800** continues with an operation **810** to calculate and accumulate an ϵ value, for example as in Equation 2. The operation **810** to accumulate the ϵ value includes any operation enabling the averaging of a number of ϵ values, including storing a number of ϵ values in a memory buffer, utilizing a filtered or weighted averaged ϵ value that captures historical ϵ value information over a number of ϵ value points, and similar operations understood in the art.

The procedure **800** further includes an operation **812** to determine whether a sufficient number of ϵ value samples have been taken. The operation to determine whether a sufficient number of samples have been taken includes determining whether a predetermined number of samples have been taken, determining whether enough samples have been taken to provide a given statistical confidence in the average of the samples, and/or may further include weighting of the confidence increment provided by each of the samples in response to the particular reliability of a given sample.

Where the procedure **800** has not resulted in a sufficient number of samples, the procedure exits the current execution cycle. Where the procedure **800** has provided sufficient samples, the procedure **800** includes an operation **814** to calculate an averaged ϵ value. The operation **814** to calculate the averaged ϵ value includes an operation to determine a statistically significant average—for example a mean or median average, an operation to utilize a moving average as the average, and/or an operation to utilize a filtered value as an average. Any other averaging operations understood in the art are contemplated herein. The procedure includes an operation **820** to clear the ϵ accumulator, which may further include resetting any filters, moving averages, or other information history parameters.

Another exemplary set of embodiments includes a procedure for monitoring a NO_x reduction catalyst conversion capability. In certain embodiments, the procedure is operable with a NO_x sensor downstream of the NO_x reduction catalyst, and no NO_x sensor upstream of the NO_x reductions catalyst. The procedure may be useful in a system having an upstream NO_x sensor, for example as a backup diagnostic for the NO_x reduction catalyst if the upstream NO_x sensor is failed or suspect. The procedure includes an operation to determine an expected NO_x emissions value—the NO_x emissions value being a NO_x emissions value downstream of the NO_x reduction catalyst (e.g. “tailpipe” NO_N). An exemplary expected NO_x emissions value is described with reference to FIGS. **10** and **11** following, wherein the diagonal line **1010**, **1110** is utilized as the expected NO_x emissions value.

The procedure further includes determining that a present engine out NO_x amount is lower than a NO_x catalyst threshold capability value and greater than a failed NO_x catalyst threshold capability value. The NO_x catalyst threshold capability value is a NO_x amount where a fully capable NO_x catalyst experiences a decreasing NO_x conversion capability due to high quantity of NO_x passing through the catalyst. The failed NO_x catalyst threshold capability value is a NO_x amount where a severely degraded NO_x catalyst will nevertheless exhibit a very high NO_x conversion due to the low quantity of NO_x passing through the catalyst. Additionally or alternatively, the high and low NO_x threshold values are further bounded by a region wherein a NO_x model is determined to be reliable. Exemplary high and low NO_x threshold values are described with reference to FIGS. **10** and **11** following. FIG. **10** depicts test cell data **1000** taken for a particular system run through a predetermined load schedule, and FIG. **11** depicts test cell data **1100** for a similar system run through a different predetermined load schedule. The data includes the engine out NO_x output **1002**, **1102** as a function of the fuel mass over charge mass **1004**. The left vertical line **1006** is selected according to the low NO_x threshold value, and the right vertical line **1008** is selected according to the high NO_x threshold value. The example thresholds **1006**, **1008** are non-limiting.

The procedure includes determining the present engine out NO_x amount in response to engine fueling, engine torque, and/or a present engine speed. Additionally or alternatively, the procedure includes determining the present engine out NO_x amount in response to an intake manifold pressure and one or more timing values of injected fuel (or spark timing for a spark-ignition engine). Any engine out NO_x model understood in the art is contemplated herein.

In one example, the low NO_x value **1006** (e.g. the failed NO_x catalyst threshold capability value) is determined at a low value of a fuel mass-flow to charge mass-flow ratio, and the high NO_x value **1008** (e.g. the NO_x catalyst threshold capability value) is determined at a high value of the fuel mass-flow to charge mass-flow ratio. When the observed fuel mass-flow to charge mass-flow ratio is between the low value and the high value, the procedure to monitor the NO_x reduction catalyst proceeds. In a further embodiment, an estimated NO_x value for the engine is determined from a calibration line **1010**, **1110** between the low value and the high value that bounds an observed engine out NO_x amount, or that bounds a majority of observed engine out NO_x amount data points.

Referencing FIG. **10**, a plot **1000** of engine-out NO_x amounts as a function of fuel mass-flow to charge mass-flow ratios are illustrated. The data points in FIG. **10** are taken from a test cell for a particular engine, and are representative of the type of data that an operator can readily determine for a given system. In the embodiment of FIG. **10**, the left vertical line **1006** is taken as the low value of a fuel mass-flow to charge mass-flow ratio, and the right vertical line **1008** is taken as the high value of a fuel mass-flow to charge mass-flow ratio. The low and high values may be determined according to the quality of the model, for example selecting logical bounding points for reliable data, and/or according to the engine-out NO_x amounts that are treatable by a properly functioning NO_x reduction catalyst (for the high value) and the engine-out NO_x amounts that would be treatable even for a failed or degraded NO_x reduction catalyst (for the low value). The diagonal line **1010** between the high and low values, in one form, is the engine-out NO_x amount estimate to be utilized in a procedure such as the procedure described in the section referencing FIG. **9**.

The procedure further includes an operation to perform a screening step, wherein a number of screening parameters are checked, and the operation to monitor the NO_x reduction catalyst NO_x conversion capability is continued if the screening parameters pass. Exemplary and non-limiting screening parameters include the NO_x reduction catalyst within a proper operational temperature, an exhaust flow of the engine being within a specified range, a rate of change of the NO_x reduction catalyst temperature being lower than a threshold value, a reductant injection command value not being limited by a system constraint (i.e. the control system for the reductant injection determination is commanding a reductant injection amount that is estimated to be sufficient to convert a designed amount of NO_x), the downstream NO_x sensor value is reading within a specified range and does not have a fault, the rate of change of the NO_x sensor value is below a threshold value, an ambient pressure is within a specified range, an estimated NH_3 slip amount is within a range or below a threshold, and an estimated NO_2 slip amount is within a range or below a threshold value. Additional screening parameters include a determination that the engine is at steady state operation, that an engine speed rate of change is below a threshold value, and/or that an engine fueling or torque value rate of change is below a threshold value.

The determination of ranges for each screening parameter depends upon the hardware present in the system, the NO_x amount that is considered for the system (e.g. due to relevant emissions limits, etc.), and is a mechanical step for one of skill in the art having the benefit of the disclosures herein. Each range and limit for the screening parameters is selected to ensure that the NO_x reduction catalyst is operating under nominal conditions wherein a properly operating catalyst should be expected to succeed and a sufficiently degraded or failed catalyst should be expected to provide insufficient NO_x reduction.

An exemplary procedure includes determining an averaged expected NO_x value and an averaged measured NO_x value from the NO_x sensor downstream of the NO_x reduction catalyst, and determining whether the NO_x reduction capability is failed in response to the averaged measured NO_x values. The averaged NO_x values may be averages of a number of values stored in a buffer, a filtered value of each parameter (with the same or distinct time constants), moving averages of the NO_x values, or values determined from other averaging mechanisms known in the art. The threshold to determine a failed NO_x conversion capability is selectable according to the specific parameters of the contemplated system, and may be a difference of 20%, 30%, 50%, or greater NO_x amounts. In certain embodiments, the difference may be a ratio difference of observed:expected NO_x (e.g. 1.2:1), an absolute value of NO_x (e.g. 10 g/hr), and/or a difference in selected units (e.g. 0.5 g/hp-hr difference).

Another exemplary procedure includes determining whether an engine-out NO_x regime is in a low, nominal, or high output region. For example, referencing FIG. **10**, the low region may be left of the left vertical line **1006**, the nominal region may be between the vertical lines **1006**, **1008**, and the high region may be to the right of the right vertical line **1008**. The exemplary procedure further includes determining whether the observed NO_x amount is higher or lower than the expected NO_x amount. Referencing FIG. **12**, an exemplary response table **1200** is illustrated for the exemplary procedure.

In response to the observed tailpipe NO_x amount being lower **1208** than the expected NO_x amount, in the low engine-out NO_x regime **1202** the procedure in region **1212** includes blocking the monitor from passing the NO_x reduction capability, or blocks the monitor from clearing a NO_x reduction capability fault. In the region **1212**, an example procedure in certain embodiments does not determine the NO_x reduction capability is failed. In response to the observed tailpipe NO_x amount being lower **1208** than the expected NO_x amount, in the nominal engine-out NO_x regime **1204**, the procedure in region **1214** determines the NO_x reduction capability is passed or allows the monitor to clear a NO_x reduction capability fault. In response observed tailpipe NO_x amount being lower **1208** than the expected NOx amount, in the high engine out NO_x region **1206**, the example procedure in the region **1216** determines the NO_x sensor to be in error or to fail a sensor rationality check.

In response to the observed tailpipe NO_x amount being higher **1210** than the expected NO_x amount, in the low engine-out NO_x regime **1202** the procedure in region **1218** determines the NO_x sensor to be in error or to fail a sensor rationality check. In response to the observed tailpipe NO_x amount being higher **1210** than the expected NO_x amount, in the nominal engine-out NO_x regime **1204**, the procedure in region **1220** determines the NO_x reduction capability is failed or allows the monitor to set a NO_x reduction capability fault. In response observed tailpipe NO_x amount being higher **1210** than the expected NO_x amount, in the high engine out NO_x region **1206**, the example procedure in the region **1222** excludes the operations from affecting any sensor or system failures, and/or from allowing faults to be set or cleared.

Referencing FIG. **9**, a schematic flow diagram illustrates a procedure **900** for monitoring a NO_x reduction system. The procedure **900** includes an operation **916** to determine whether an engine fuel flow **902** and an engine mass flow **904** are below threshold values to perform a monitoring check of the NO_x reduction system. The procedure **900** further includes an operation **918** to determine whether the rate of change of the engine fuel flow **902** and the engine mass flow

904 are below threshold values to perform the monitoring check of the NO_x reduction system. The threshold values for the engine fuel flow 902 and engine mass flow 904, and the rates of change thereof, may be set for any reason, including without limitation controlling the test to occur within certain power or emissions limits, within certain catalyst space velocity limits, and/or within certain exhaust temperature limits. The outputs of the operations 916, 918 are input as logical values to an AND block 926. The procedure 900 further includes an operation 922 to determine whether a value of a

$$\frac{FuelFlow}{ChargeFlow}$$

is between a high and low threshold. The value

$$\frac{FuelFlow}{ChargeFlow}$$

may be determined according to any method; a lookup table utilizing fuel massflow 902 and charge massflow 904 is consistent with the depiction in the example. The procedure 900 further includes operations to determine whether data screening parameters 920 have values indicating the monitor should be performed.

In response to all of the logical values for the determining operations entering the AND block 926 being TRUE, the procedure 900 includes an enable operation 928 for each of the operations 932, 934. The procedure 900 further includes an operation 912 to determine an expected NO_x emissions value 914. The example operation 912 utilizes an engine speed 916, an engine torque 918, and a weighting factor 910. The weighting factor 910 may be determined in response to various engine operation conditions, including at least an EGR fraction, a charge temperature, the timing of fueling, and/or a fuel rail pressure. Additionally or alternatively, any NO_x model to determine an expected NO_x emissions value is contemplated herein.

The procedure 900 further includes, in response to the enabling operation 928, calculating an average value of the expected NOx tailpipe a first operation 932 to calculate an average of a number of values of an expected NO_x calculation over a period of time or execution cycles, and a second operation 934 to calculate an average of a number of values of a NO_x sensor reading 930 over the period of time or execution cycles. The NO_x sensor reading is interpreted from a NO_x sensor positioned downstream of the NO_x reduction catalyst of the NO_x reduction system. The procedure 900 further includes an operation 936 to compare the averaged values, and an operation 938 to determine a fault value (increment, set, decrement, and/or clear) in response to the comparison.

An example set of embodiments is a method including determining whether a urea refill event is detected, and in response to the refill event being detected, clearing a urea quality accumulator value and clearing a latching abort command. The method includes determining whether urea fluid quality check abort conditions are met, and in response to the abort conditions being met, clearing the urea quality accumulator, latching the abort command, and exiting the reductant fluid quality check. The method further includes, in response to the abort conditions not being met, incrementing the urea quality accumulator according to an amount of urea being injected. The method further includes comparing the accumulated urea quantity to a low test threshold, and in response to the accumulated urea quantity being less than the low test threshold, exiting the current execution cycle of the reductant fluid quality check. The method further includes, in response to the accumulated urea quantity being greater than the low test threshold, comparing the accumulated urea quantity to a high test threshold, and in response to the urea quantity being greater than the high test threshold, determining whether the a NO_x exceedance is observed and clearing a urea quality error in response to the NO_x exceedance not being observed.

Certain further embodiments of the example method are described following. An example method includes in response to the accumulated urea quantity being less than the high test threshold, determining whether the a NO_x exceedance is observed and setting a urea quality error in response to the NO_x exceedance being observed and clearing the urea quality error in response to the NO_x exceedance not being observed. An example method includes determining an averaged ϵ value including ANR/deNO_x η values taken at ammonia-to-NO_x ratio (ANR) values below a β value, wherein β is approximately a stoichiometric ANR value, determining an averaged deNO_x η value comprising deNO_x η values taken above the β value, and in response to the averaged ϵ value and the averaged deNO_x η value, determining whether a NO_x reduction system is in a PASS or FAIL state. An example method further includes determining the state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO_x η value comprises determining the NO_x reduction system is in a PASS state in response to the averaged ϵ value and the averaged deNO_x η value both indicating a passing value. Additionally or alternatively, the method includes determining the state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO_x η value by determining the NO_x reduction system is in a failed state, with the failure being at least one of a urea injector and the urea in response to the averaged ϵ value indicating a failing value and the averaged deNO_x η value indicating a passing value. In certain embodiments, the method includes determining the failure to be a urea injector in response to the urea fluid quality error being one of cleared and not set.

An example method includes determining the state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO_x η value by determining the NO_x reduction system is in a failed state, with the failure being at least one of a NO_x reduction catalyst and the urea in response to the averaged ϵ value indicating a failing value and the averaged deNO_x η value indicating a passing value. In certain embodiments, the method further includes determining the failure to be a NO_x reduction catalyst in response to the urea fluid quality error being one of cleared and not set. In certain embodiments, the averaged deNO_x η value includes a normalized deNO_x η value. An example method includes each ϵ value determined for the averaged ϵ value being determined according any one of the terms selected from the equation:

$$\varepsilon = \frac{\mathrm{NH_3\_in}}{\mathrm{NOx\_in} - \mathrm{NOx\_out}} = \frac{\mathrm{NH_3\_in/NOx\_in}}{(\mathrm{NOx\_in} - \mathrm{NOx\_out})/\mathrm{NOx\_in}} = \frac{ANR}{\mathrm{DeNOx\_eff}};$$

where NH_{3_in} is the NH_3 concentration into the deNO_x catalyst, wherein NO_{x_in} is the NO_x concentration into the deNO_x catalyst, wherein the NO_{x_out} is the NO_x concentration out of the deNO_x catalyst.

An example method includes each deNO_x η value determined for the averaged deNO_x η value being determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out})/NO_{x\_in}}{\eta_{nominal}}.$$

where $\eta_{Normalized}$ is the deNO$_x$ η value, and wherein $\eta_{nominal}$ is an expected deNO$_x$ efficiency.

Another example set of embodiments is a method including determining whether an engine fuel massflow and an engine charge massflow have values below threshold values, determining whether the engine fuel massflow and an engine charge massflow have rates of change below threshold values, determining whether a number of data screening parameters have values indicating that a NOx reduction system monitor operation can be performed, and determining whether a value of

$$\frac{FuelFlow}{ChargeFlow}$$

is between a high and low threshold. The method further includes, in response to all of the logical values for the determining operations being TRUE, calculating an average of a number of values of an expected NO$_x$ calculation over a period of time or execution cycles, and calculating an average of a number of values of a NO$_x$ sensor reading over the period of time or execution cycles. The method includes comparing the averaged values and determining a fault value for a NO$_x$ reduction system NO$_x$ conversion capability in response to the comparing.

Certain further embodiments of the method are described following. An example method includes calculating an average of a number of values of an expected NO$_x$ calculation over a period of time or execution cycles by operating a NO$_x$ reduction model of the NO$_x$ reduction system. an example method includes calculating an average of a number of values of an expected NO$_x$ calculation over a period of time comprises using lookup values from a predetermined function of engine out NOx values as a function of

$$\frac{FuelFlow}{ChargeFlow}$$

values. In certain further embodiments, the method includes the high and low thresholds of the

$$\frac{FuelFlow}{ChargeFlow}$$

being validated operating ranges for the predetermined function, and/or the predetermined function being a linear increasing function with

$$\frac{FuelFlow}{ChargeFlow}.$$

Yet another example set of embodiments is a method including determining an averaged ϵ value comprising ANR/deNO$_x$ η values taken at ammonia-to-NO$_x$ ratio (ANR) values below a β value, where β is approximately a stoichiometric ANR value for a NO$_x$ reduction system fluidly coupled to the exhaust of an internal combustion engine, determining an averaged deNO$_x$ η value being deNO$_x$ η values taken above the β value, and in response to the averaged ϵ value and the averaged deNO$_x$ η value, determining whether the NO$_x$ reduction system is in a PASS or FAIL state. In certain embodiments, the method includes determining the state of the NO$_x$ reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value by determining that the NO$_x$ reduction system is in a PASS state in response to the averaged ϵ value and the averaged deNO$_x$ η value both indicating a passing value. Additionally or alternatively, the method includes determining the state of the NO$_x$ reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value by determining the NO$_x$ reduction system is in a failed state, with the failure being at least one of a urea injector and a urea fluid quality, in response to the averaged ϵ value indicating a failing value and the averaged deNO$_x$ η value indicating a passing value, where the urea is a reductant fluid for the NO$_x$ reduction system and the urea injector is operationally coupled to the exhaust at a position upstream of a selective reduction catalyst. In certain further embodiments, the method includes determining the failure to be the urea injector in response to a urea fluid quality check passing the urea fluid quality.

In certain embodiments, the method includes determining the state of the NO$_x$ reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value by determining the NO$_x$ reduction system is in a failed state, with the failure being at least one of a NO$_x$ reduction catalyst and the urea, in response to the averaged 8 value indicating a failing value and the averaged deNO$_x$ η value indicating a passing value. In certain embodiments, the method includes determining the failure to be a NO$_x$ reduction catalyst in response to the urea fluid quality check passing the urea fluid quality. Additionally or alternatively, the averaged deNO$_x$ η value is a normalized deNO$_x$ η value.

In certain embodiments, the method includes each ϵ value determined for the averaged ϵ value to be determined according any one of the terms selected from the equation:

$$\varepsilon = \frac{\mathrm{NH_3\_in}}{\mathrm{NOx\_in - NOx\_out}} = \frac{\mathrm{NH_3\_in/NOx\_in}}{\mathrm{(NOx\_in - NOx\_out)/NOx\_in}} = \frac{ANR}{\mathrm{DeNOx\_eff}};$$

where NH_{3_in} is the NH_3 concentration into the deNO$_x$ catalyst, wherein NO_{x_in} is the NO$_x$ concentration into the deNO$_x$ catalyst, wherein the NO_{x_out} is the NO$_x$ concentration out of the deNO$_x$ catalyst. In certain embodiments, the method includes each deNO$_x$ η value determined for the averaged deNO$_x$ η value to be determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out})/NO_{x\_in}}{\eta_{nominal}}$$

where $\eta_{Normalized}$ is the deNO$_x$ η value, and wherein $\eta_{nominal}$ is an expected deNO$_x$ efficiency.

Still another example set of embodiments is a system including an internal combustion engine having an exhaust, a NO$_x$ reduction system having a selective catalytic reduction (SCR) catalyst, and a reductant injector operationally coupled to the exhaust at a position upstream of the SCR catalyst and receiving reductant from a reductant source. The system includes a means for determining a failure in one of the reductant injector, the SCR catalyst, and the reductant. In certain embodiments, the system includes the means for determining a failure further including a means for distinguishing a failure source between the reductant injector, the SCR catalyst, and the reductant. In still further embodiments, the system includes the means for determining a reductant failure including means for detecting a reductant source refill event, and accumulating an amount of reductant injected over a period of time following the reductant source refill event. In certain further embodiments, the system includes the means for determining a failure of the reductant injector in response to: a failed ϵ value, a passed normalized $deNO_x$ efficiency value, and the determining the failure of the reductant determines that the reductant is not failed. Additionally or alternatively, the system includes a means for determining a failure of the SCR catalyst in response to: a passed ϵ value, a failed normalized $deNO_x$ efficiency value, and the determining the failure of the reductant determines that the reductant is not failed.

Yet another example set of embodiments is a system including an internal combustion engine having an exhaust, a NO_x reduction system having a selective catalytic reduction (SCR) catalyst, a reductant injector operationally coupled to the exhaust at a position upstream of the SCR catalyst and receiving reductant from a reductant source, and a means for determining a failure in the NO_x reduction system in response to an engine-out NO_x amount and a NO_x measurement at a position downstream of the SCR catalyst. In certain embodiments, the means for determining a failure in the NO_x reduction system determines the NO_x reduction system is passed in response to the engine-out NO_x amount in a middle range and the NO_x measurement in a low range. Additionally or alternatively, the means for determining a failure in the NO_x reduction system determines the NO_x reduction system is failed in response to the engine-out NO_x amount in a middle range and the NO_x measurement in a high range. In certain embodiments, the means for determining a failure in the NO_x reduction system determines a NO_x sensor providing the NO_x measurement is failed in response to the engine-out NO_x amount in a high range and the NO_x measurement in a low range. In certain embodiments, the means for determining a failure in the NO_x reduction system determines a NO_x sensor providing the NO_x measurement is failed in response to the engine-out NO_x amount in a low range and the NO_x measurement in a high range.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the inventions are desired to be protected. In reading the claims, it is intended that when words such as "a," "an," "at least one," or "at least one portion" are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language "at least a portion" and/or "a portion" is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

What is claimed is:

1. A method for performing a reductant fluid quality check in a NO_x reduction system with a controller, the NO_x reduction system comprising a urea tank with the urea and a urea tank level sensor, the NO_x reduction system further comprising a NO_x reduction catalyst and a NO_x sensor downstream of the NO_x reduction catalyst, wherein the urea tank is con-ted to a urea injector for injection of the urea upstream of the NO_x reduction catalyst, the method comprising:

refilling the urea tank;

outputting a signal from the urea tank level sensor indicating a urea refill event for urea in the urea tank of the NO_x reduction system is detected;

determining whether urea fluid quality check abort conditions are met in response to the urea refill event being detected;

in response to the urea fluid quality check abort conditions being met, clearing a urea quantity accumulator value in the controller, clearing a latching abort command in the controller, and exiting a urea fluid quality check operable by the controller;

passing an exhaust flow with NO_x through the NO_x reduction catalyst and outputting a signal from the NO_x sensor of a NO_x amount measured downstream of the NO_x reduction catalyst;

injecting an amount of urea from the urea tank with the urea injector upstream of the NO_x reduction catalyst of the NO_x reduction system and in response to the urea fluid quality check abort conditions not being met incrementing the urea quantity accumulator value according the amount of urea;

comparing an accumulated urea quantity injected by the urea injector from the urea tank to a low test threshold, and in response to the accumulated urea quantity being less than the low test threshold, exiting a current execution cycle of the urea fluid quality check;

in response to the accumulated urea quantity being greater than the low test threshold, comparing the accumulated urea quantity injected by the urea injector from the urea tank to a high test threshold, and in response to the accumulated urea quantity injected from the urea tank by the urea injector being greater than the high test threshold, determining from the signal output by the NO_x sensor whether a NO_x exceedance out of the NO_x reduction catalyst is observed and clearing a urea quality error in the controller in response to the NO_x exceedance not being observed.

2. The method of claim **1**, further comprising, in response to the accumulated urea quantity being less than the high test threshold, determining whether the NO_x exceedance is observed and setting a urea quality error in response to the NO_x exceedance being observed and clearing the urea quality error in response to the NO_x exceedance not being observed.

3. A method of claim **1**, the method further comprising determining an averaged ϵ value comprising ANR/$deNO_x$ η values taken at ammonia-to-NO_x ratio (ANR) values below a β value, wherein β is a stoichiometric ANR value;

determining an averaged $deNO_x$ η value comprising $deNO_x$ η values taken above the β value; and

in response to determining the averaged ϵ value and the averaged $deNO_x$ η value, determining the NO_x reduction system is in a PASS state or a FAIL state.

4. The method of claim **3**, wherein determining the PASS state or the FAIL state of the NO_x reduction system in response to the averaged ϵ value and the averaged $deNO_x$ η value comprises determining the NO_x reduction system is in the PASS state in response to the averaged ϵ value and the averaged $deNO_x$ η value both indicating a passing value.

5. The method of claim **3**, wherein determining the PASS irate or the FAIL state of the NO_x reduction system in response to the averaged ϵ value and the averaged $deNO_x$ η value comprises determining the NO_x reduction system is in a failed state, with the failed state being at least one of the urea injector and the urea in response to the averaged ϵ value indicating a failing value and the averaged $deNO_x$ η value indicating a passing value.

6. The method of claim 5, further comprising determining the failed state to be the urea injector in response to the urea fluid quality error being one of cleared and not set.

7. The method of claim 3, wherein determining the PASS state or the FAIL state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value comprises determining the NO_x reduction system is in a failed state, with the failed state being at least one of the NO_x reduction catalyst and the urea in response to the averaged ϵ value indicating a passing value and the averaged deNO$_x$ η value indicating a failing value.

8. The method of claim 7, further comprising determining the failed state to be the NO_x reduction catalyst in response to the urea fluid quality error being one of cleared and not set.

9. The method of claim 3, wherein the averaged deNO$_x$ η value comprises a normalized deNO$_x$ η value.

10. The method of claim 3, wherein ϵ values for the averaged ϵ value are determined according any one of the equations:

$$\varepsilon = \frac{\text{NH}_3\text{\_in}}{\text{NOx\_in} - \text{NOx\_out}} = \frac{\text{NH}_3\text{\_in}/\text{NOx\_in}}{(\text{NOx\_in} - \text{NOx\_out})/\text{NOx\_in}} = \frac{ANR}{\text{DeNOx\_eff}};$$

wherein NH_{3_in} is an NH_3 concentration into the NO_x reduction catalyst, wherein NO_{x_in} is an NO_x concentration into the NO_x reduction catalyst, wherein the NO_{x_out} is an NO_x concentration out of the NO_x reduction catalyst, wherein ANR is an ammonia-to-NO_x ratio value, and wherein DeNO$_x$_eff is a NO_x removal efficiency of the NO_x reduction catalyst.

11. The method of any one of claim 9, wherein a deNO$_x$ η value determined for the averaged deNO$_x$ η value is determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out})/NO_{x\_in}}{\eta_{nominal}}$$

wherein $\eta_{Normalized}$ is the deNO$_x$ η value, and wherein $\eta_{nominal}$ is an expected deNO$_x$ efficiency, wherein NO_{x_in} is a NO_x concentration into the NO_x reduction catalyst, wherein NO_{x_out} is a NO_x concentration out of the NO_x reduction catalyst.

12. A method for performing a check of a NO_x reduction system with a controller, the NO_x reduction system comprising a urea tank for storing urea and a urea tank level sensor, the NO_x reduction system further comprising a NO_x reduction catalyst and a urea injector operationally coupled for injection of urea upstream of the NO_x reduction catalyst, the NO_x reduction system further comprising at least one NO_x sensor and the method comprising:

operating an internal combustion engine to produce an exhaust flow with NO_x that is received by the NO_x reduction system;

injecting urea from the urea tank into the exhaust flow upstream of the NO_x reduction catalyst with the urea injector;

outputting a signal from the at let one NO_x sensor indicative of a NO_x amount downstream of the NO_x reduction catalyst;

outputting an engine out NO_x amount and an ammonia amount upstream of the NO_x reduction catalyst;

determining, with the controller in response to the signal indicating the NO_x amount downstream of the NO_x reduction catalyst, the engine out NO_x amount and the ammonia amount, an averaged ϵ value for the NO_x reduction catalyst comprising ANR/deNO$_x$ η values taken at ammonia-to-NO_x ratio (ANR) values below a β value, wherein β is a stoichiometric ANR value for the NO_x reduction system;

determining an averaged deNO$_x$ η value for the NO_x reduction catalyst comprising deNO$_x$ η values taken above the β value during operation of the internal combustion engine; and

in response to determining the averaged ϵ value and the averaged deNO$_x$ η value, outputting a signal from the controller indicating that the NO_x reduction system is in one of a PASS state or a FAIL state.

13. The method of claim 12, wherein determining the PASS state or the FAIL state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value comprises determining the NO_x reduction system is in the PASS state in response to the averaged ϵ value and the averaged deNO$_x$ η value both indicating a passing value.

14. The method of claim 12, wherein determining the PASS state or the FAIL state of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value comprises determining the NO_x reduction system is in a failed state, with the failed state being at least one of the urea injector and a urea fluid quality of the urea in response to the averaged ϵ value indicating a failing value and the averaged deNO$_x$ η value indicating a passing value.

15. The method of claim 14, further comprising determining the failed state to be the urea injector in response to a urea fluid quality check passing the urea fluid quality.

16. The method of claim 12, wherein determining the PASS state or the FAIL of the NO_x reduction system in response to the averaged ϵ value and the averaged deNO$_x$ η value comprises determining the NO_x reduction system is in a failed state, with the failed state being at least one of the NO_x reduction catalyst and the urea in response to the averaged ϵ value indicating a passing value and the averaged deNO$_x$ η value indicating a failing value.

17. The method of claim 16, further comprising determining the failure to be the NO_x reduction catalyst in response to the urea fluid quality check passing the urea fluid quality.

18. The method of claim 12, wherein the averaged deNO$_x$ η value comprises a normalized deNO$_x$ η value.

19. The method of claim 12, wherein ϵ values for the averaged ϵ value are determined according any one of the following equations

$$\varepsilon = \frac{\text{NH}_3\text{\_in}}{\text{NOx\_in} - \text{NOx\_out}} = \frac{\text{NH}_3\text{\_in}/\text{NOx\_in}}{(\text{NOx\_in} - \text{NOx\_out})/\text{NOx\_in}} = \frac{ANR}{\text{DeNOx\_eff}};$$

wherein NH_{3_in} is an NH_3 concentration into a NO_x reduction catalyst, wherein NO_{x_in} is an NO_x concentration into the NO_x reduction catalyst, wherein an NO_{x_out} is the NO_x concentration out of the NO_x reduction catalyst, wherein ANR is an ammonia-to-NO_x ratio value, and wherein DeNO$_x$_eff is a NO_x removal efficiency of the NO_x reduction catalyst.

20. The method of claim 12, wherein a deNO$_x$ η value determined for the averaged deNO$_x$ η value is determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out})/NO_{x\_in}}{\eta_{nominal}}$$

wherein $\eta_{Normalized}$ is the deNO$_x$ η value, and wherein $\eta_{nominal}$ is an expected deNO$_x$ efficiency, wherein NO$_{x_in}$ is an NO$_x$ concentration into the NO$_x$ reduction catalyst, wherein an NO$_{x_out}$ is the NO$_x$ concentration out of the NO$_x$ reduction catalyst.

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